# Rotary Kilns

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PT 98/14362/E

## SUMMARY

After over 100 years, the rotary kiln is used in all cement plants for clinker production.

The following properties made it superior to other principles:

- suitable to cope with high temperatures
- easy to be lined with refractory bricks due to its shape
- material transport behaviour
- tight to ambient
- mechanically relatively simple
- large units possible

The rotary kiln must be designed for process, combustion and mechanical requirements.

| | | |
|---|---|---|
| Characteristic figures: | Length L [m] , diameter D [m] and their ratio L/D [-] | |
| | Slope [°], speed range [$min^{-1}$] and drive [kWh] | |
| Dimensioning criteria: | Volume load | [t/(d m3)] |
| | Burning zone load | [t/(d m2)] |
| | Thermal burning zone load | [MW/m2] |

Important mechanical features are:

- riding ring fixation
- roller station / alignment
- seals at inlet and outlet
- drive

With modern precalciner technology, outputs exceeding 10'000 t/d per kiln are possible with diameters still below the 6.5 m of the largest wet kilns.

There is a trend towards short L/D kilns with only two piers mainly because of lower investment.

## 1. GENERAL

Today, all clinker producing installations of industrial size use a rotary kiln. The rotary kiln is still the only feasible way to manage this high temperature process with process material of varying behaviour.

One exception is the vertical shaft kiln still used in some parts of the world, e.g. China, however, for small unit capacities only. The other exceptions are few pilot installations based on sintering in a fluidized bed reactor.

Like many other great ideas, the rotary kiln was invented towards the end of the 19th century and has found application in many different industries. In 1987, Hurry and Seaman in the USA developed the first successfully working rotary kiln to produce cement clinker.

The first rotary cement kilns were using the wet process with one very long kiln tube, making it the dominating single piece of equipment of a plant. With technological progress, the kiln sections used for for drying, heating-up and calcining have gradually been replaced by other types of equipment, the rotary kiln remains to be the most suitable type of machine for the clinkerization process.

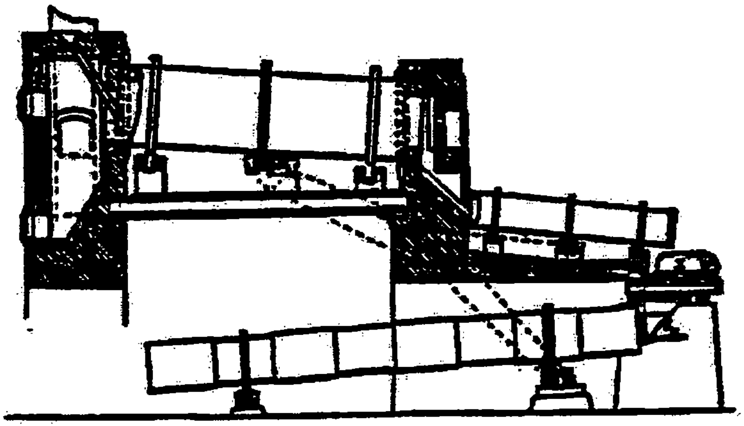
The rotary kiln has to satisfy three types of requirements:

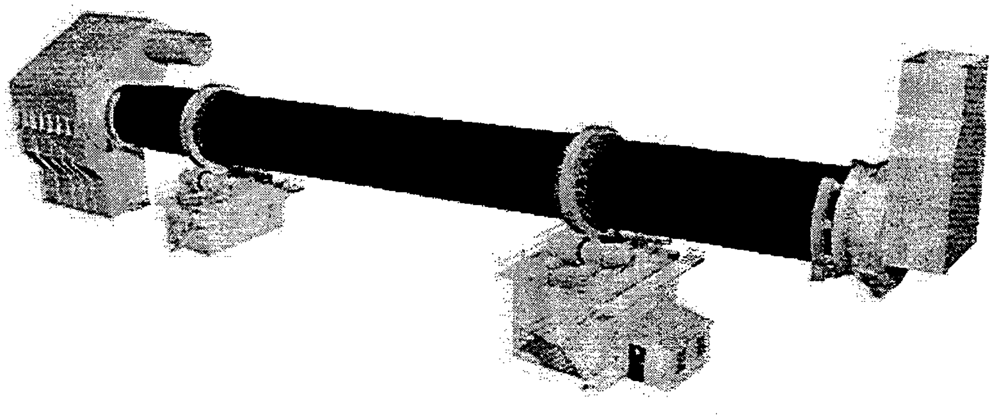
| | | |
|---|---|---|
| **Combustion:** | as a combustion chamber for burning zone fuel | |
| **Process:** | as a reactor for the clinker burning process | (→ retention time) |
| | as a material conveyor | (→ slope, speed) |
| **Mechanical:** | stability of shape, carrying load, thermal flexibility, tightness | |

*Remarks:*

- *Even though the rotary kiln is a relatively simple piece of equipment, nobody has developed a complete theoretical/mathematical model of its behaviour and process which would allow correct process simulation and equipment design.*
- *The rotary kiln is still the "heart" of the entire production line. Its OEE (overall equipment efficiency) depending mainly on hourly output and availability, is decisive for the success of a plant.*
- *The rotary kiln is designed to operate 24 hours a day, and the rest of the equipment upstream and downstream has to follow.*
- *Being a major cause for production cost (mechanical maintenance, refractories), a well managed kiln is vital for a successful plant.*

**Figure 1: Old and new kiln**





**Latest kiln technology : short L/D kiln with 2 piecs and friction drive (FLS)**

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## 2. KILN DIMENSIONING

The kiln dimensions are defined with diameter D (for kilns with different diameter: burning zone D) and length L:

L [m] and D [m]     resp.     L/D [m]

- For cement kilns, the actual L/D ratio range is:
  from **40** (for long wet kilns) to **11** (for modern short kilns with precalciner)
- The diameter D is the inner diameter $D_i$ of the kiln (steel-) shell.
- Process technological dimensioning of a kiln is based on empirical figures and experience from existing installations

One limiting factor for the diameter is the mechanical stability of the 'arch' of the brick lining. Maximum diameters which can be safely realised with standard size bricks are about 6,5 m. The largest kiln in the "Holderbank" group is 232 m (wet process, 3750 t/d).

The following process technological dimensioning criteria are mostly used:

| | | |
|---|---|---|
| Specific Volume Load | $\frac{\text{Clinker Production}}{\text{Net Kiln Volume}}$ | $[t/(d\ m^3)]$ < 5,5 |
| Specific Zone Load | $\frac{\text{Clinker Production}}{\text{Net Burning Zone Cross Section}}$ | $[t/(d\ m^2)]$ < 350 |
| Thermal Burning Zone Load | $\frac{\text{Burning Zone Heat Input}}{\text{Net Bruning Zone Cross Section}}$ | $[MW/m^2)]$ < 6.0 |

Specific volume load and thermal burning zone (BZ) load have no physical significance. They are merely defined to make existing installations comparable.

The specific load is indirectly a gas velocity, because generating a certain amount of thermal energy by fuel combustion results in a proportional gas flow which can be calculated.

The thermal BZ load per cross section is considered the limiting factor for a modern kiln system. For a certain length/diameter ratio, which is typical for each kiln type, the thermal BZ load it is proportional to the heat load on the inside of the lining surface which is one of the main influencing factor on brick life. The limit usually respected is:

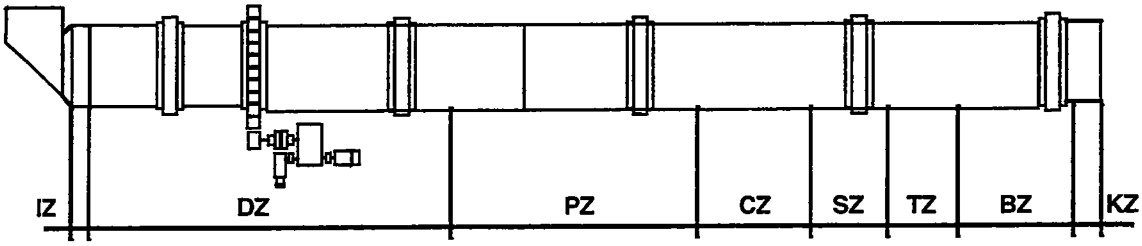
**Max. Thermal BZ Load = 6 $MW/m^2$ (=5.16 x $10^6$ $kcal/m^2$ h)**

Other absolute limiting values of all the three factors are not known. Each supplier seems to have his own rules of kiln dimensioning. Since no theoretical formulas have been derived to calculate the kiln size on an analytical basis, it is possible, that the present limits of the dimensioning criteria may be surpassed even for the conventional processes.

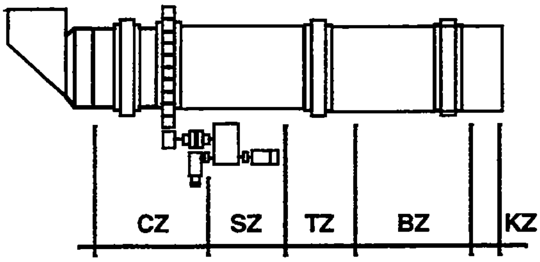
**Figure 2:** **Long and short L/D kilns**

# Rotary kiln zones

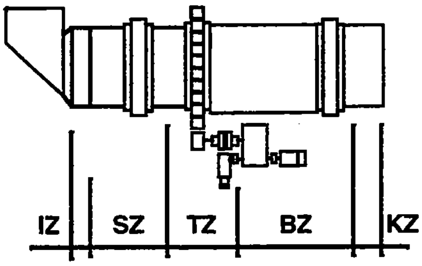
**L/D = 30 (long wet kiln)**




**L/D = 15 (dry preheater kiln)**




**L/D = 11 (short dry PC kiln)**




**DZ = Drying zone**
**PZ = Preheater zone**
**CZ = Calcining zone**
**SZ = Safety zone**
**TZ = Transition zone**
**BZ = Burning (sintering) zone**
**KZ = Kiln internal cooling zone**

## 3. MECHANICAL ASPECTS OF ROTARY KILNS

The following aspects of kiln mechanical design are relevant for the process:

- Riding ring fixation, kiln shell ovality
- Kiln seals
- kiln drive
- refractory lining (separate paper)
- nose ring (covered in "refractory lining")

### 3.1 Riding Ring Fixation, Kiln Shell Ovality

A rotary kiln should be designed as cheaply as possible, yet it must still be rigid to guarantee minimum wear of the lining. This requirement can be met, if the deformation of the kiln shell is reduced to a tolerable limit.

The parameter expressing shell deformation at a certain point is the kiln shell ovality $\omega$:

Definition of $\omega$: $\omega = 2 (a - b)$ with 2a and 2b as the main axis of an ellipse

Investigations have shown, that generally a maximum relative ovality $\omega$ of 0,3% is allowed
This ovality may be subdivided into two amounts:

a) Ovality of the riding ring 3 cm due to external forces allowed value:

$$\frac{\omega}{dr} <= 0.2\%$$

a) Ovality of the kiln shell due to deformations by its own weight in loose riding rings and due to increased temperature.

The following two requirements must be met to keep the kiln ovality within the tolerable limits:

- The riding rings must be rigid enough
- The clearance between the ring shoes and the riding ring should be minimum during operation. The following table shows some practical values:

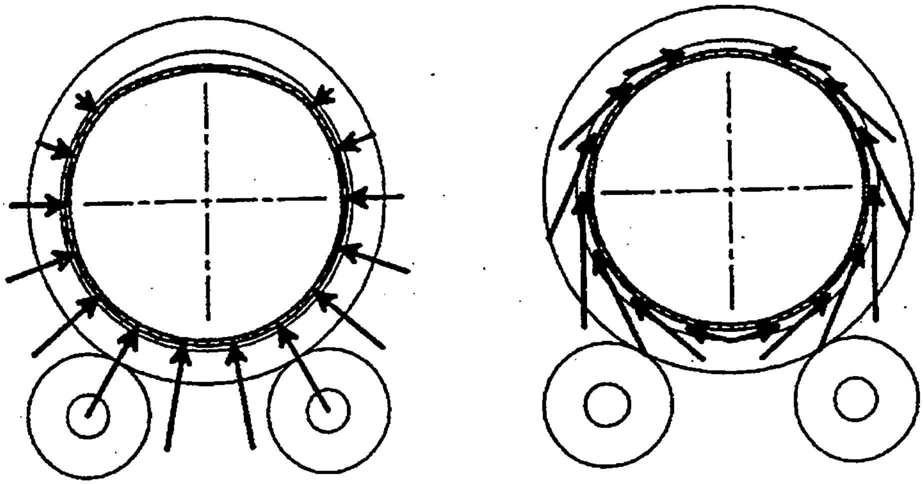
| | | | | |
|---|---|---|---|---|
| Riding Ring No. | 1 | 2 | 3 | 4 |
| Clearance during operation [mm]<br>maximum [mm] | 3-4 | 3-4 | 4-6<br>10-15 | 5-6 |

Riding rings with splined fixation provide much better support of the kiln shell. Because the kiln shell is laterally suspended in adequately designed carrying bars, ovality is much reduced resulting in noticeably better brick life.

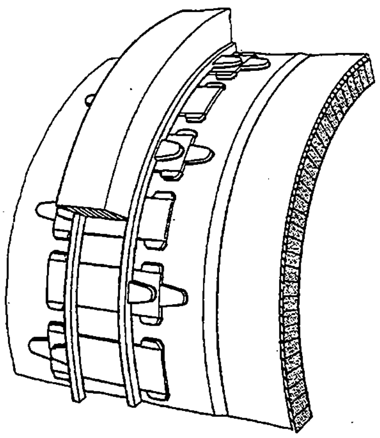
Such systems are currently available from Polysius and FLS, the latter one is lso offered as retrofit. Splined tire fixations are integral part of gearless kiln drive systems.

**Figure 3: Tire fixations**

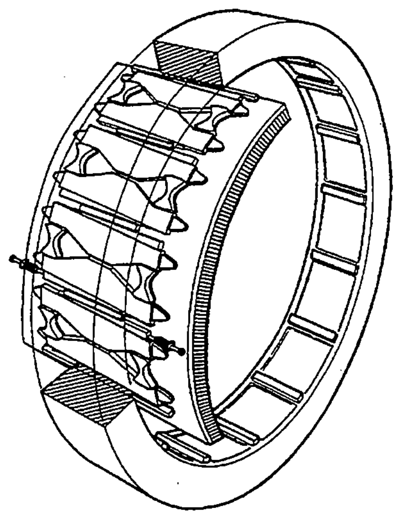
### Kiln tire fixation



### Loose tire fixation



### Splined tire fixation



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## 3.2 Kiln Seals

In order to avoid the danger of hot gases and dust leaking into the atmosphere, the entire kiln system is operated at negative pressure. The pressure profile starts at ambient (grate cooler: above first grate, satellite and tube cooler: fresh air inlet) and becomes increasingly negative towards the kiln induced draft (ID) fan.

Instead of leaking out from within the process, there is now a problem with ambient air being sucked into the system, called false air. Depending on the point of entry, false air has different undesired effects. That is why a lot of effort is made to keep process systems tight.

### 3.2.1 Kiln Inlet Seal

The kiln inlet seal (inlet: referring to material flow) is at point with negative pressure of less than 10 mmWG (modern 2-support kilns) up to 100 mmWG (long wet kilns with chains).

Modern kilns with low suction have high temperatures (up to 1300°C) instead.

False air entering the system causes

- Additional gas to be handled by kiln ID fan and dedusting system
- Unnecessary cooling of hot process gases reducing value of heat

*Kiln inlet seals:*

- Sealing force by pneumatic cylinders (pneumatic); sealing-rings
- Sealing force by coil springs/levers or weights (mechanical); sealing-segments
- Sealing force by leaf springs and rope with weight; lamella (fish scale)

Kiln inlet seals must be equipped with a dust return scoop ring to avoid spillage of kiln feed.

*Note:*

*The inlet seal is designed to seal against cold fresh air from outside, but it can be damaged if it must seal hot gas from inside to ambient in case of system overpressure! (this happens sometimes during the heating-up phase)*

### 3.2.2 Kiln Outlet Seal

With grate and tube coolers, the kiln outlet seal is installed between kiln head and rotary kiln where pressure should be slightly negative. Kiln outlet seals used with grate coolers must be designed to cope with pressure pulsation with occasional positive pressure. Outlet seal and nosering (brick retainer) with cooling air fan can be considered one system.

Here, the loss generated by false air reduces recuperation from the clinker cooler. Cold ambient air replaces hot secondary air from the cooler which has to be vented.

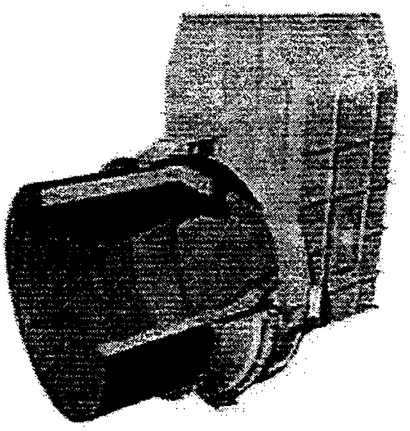
Outlet seals designed specifically for this application of the following type are available:

- Pneumatic
- Mechanical
- Lamella (fish scale)
- Labyrinth (outdated)

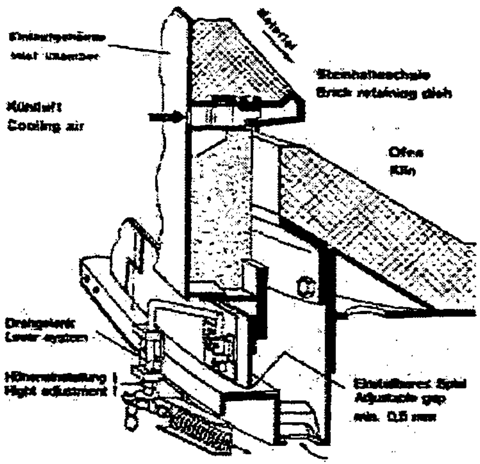
With planetary coolers, false air reduces the amount of cooling air resulting in higher clinker temperatures. The outlet seal is smaller, at lower temperature and negative pressure only.

**Figure 4: Kiln seals**

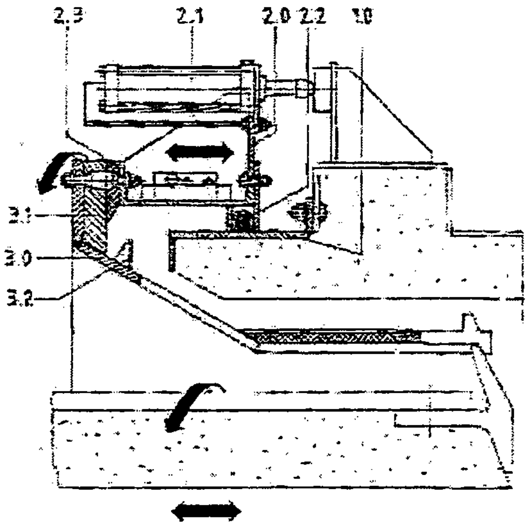
# Kiln seals



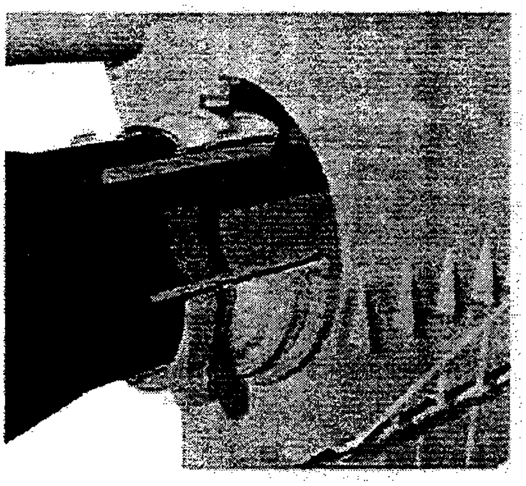
**Lamella inlet real**




**Mechanical inlet real**




**Pneumatic outlet real**



**Lamella outlet real**

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### 3.3 Kiln Drive

Kiln drives are designed for speeds between 1.0 and 4.0 $min^{-1}$, depending on slope, process and kiln dimensions. Long wet kilns are typically operated at the low end of this speed range where some new high performance kilns (short L/D with precalciners) are running at the upper end.

For over 10 years, rotary kilns have been driven by girth and pinion type drives. Decisive for their performance are:

- Correct dimensioning
- Correct alignment (even load distribution on the flanks of the teeth; no peaks)
- Adequate lubrication system and lubricant quality

With the new two support short kilns (L/D < 13) with long overhangs, kiln shell deformation and burning zone much closer to the drive, it became more difficult to ascertain correct alignment. Because of the determined load distribution on two piers, it became possible to avoid the girth drive by using the kiln rollers to transfer the torque to the riding ring: the gearless drive (=friction drive) was introduced. It is currently available from Polysius (POLRO) and FLS-Fuller (ROTAX).

The following elements are part of this system:

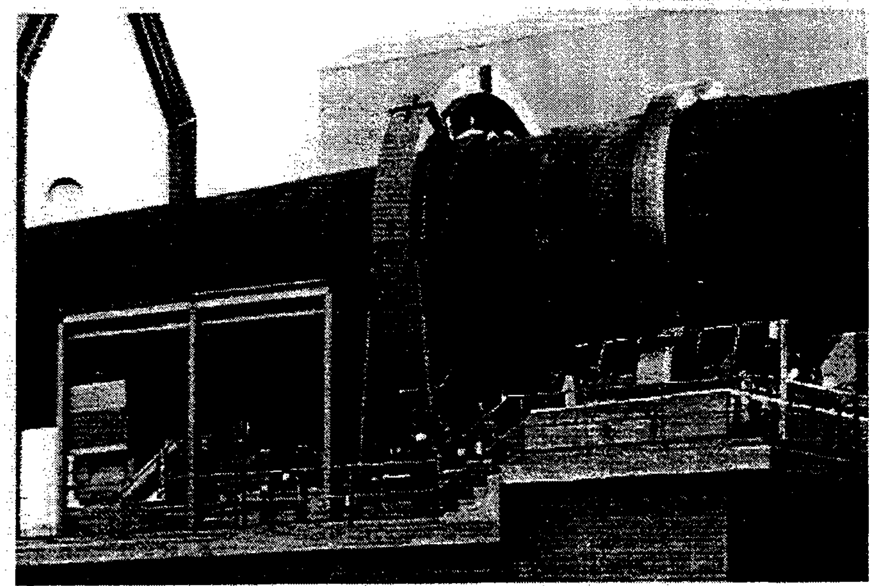
| | |
|---|---|
| • Two supports | for defined load on the driven tire |
| • Splined tire fixation | for safe torque transmission to the shell |
| • Self-aligning roller station | for linear load pattern between roller and tire (friction) |

Today, there are only few kilns with friction in operation; the first one was Lägerdorf 11 by Polysius. Detail optimization and long term experience are yet to be awaited.

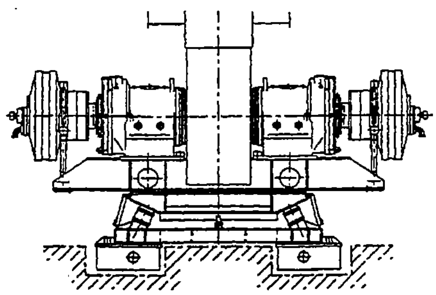
Most systems have hydraulic drives for two rollers. This provides smooth operation, but is expensive, rather complex (hydraulic unit) and has higher power consumption. Electric direct drive of only one roller has been installed in one case.

**Figure 5: Kiln drives**

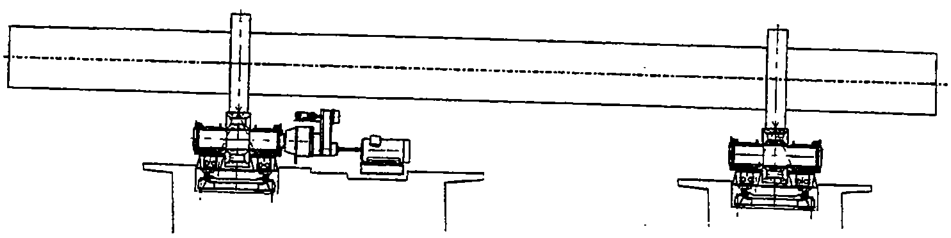
# Kiln drives



Girth and pinion drive



Gearless (friction) drive



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